Contents

List of Examples xv

List of Figures xvii

List of Tables xix

About This Guide xxi
Who This Guide Is For xxi
What the Book Contains xxii
Other Useful Books xxiii

1. Real-Time Programs 1
Defining Real-Time Programs 1
Major Types of Real-Time Programs 1
Simulators 2
Requirements on Simulators 2
Frame Rate 3
Transport Delay 3
Aircraft Simulators 3
Ground Vehicle Simulators 4
Plant Control Simulators 4
Virtual Reality Simulators 4
Hardware-in-the-loop (HITL) Simulators 5
Data Collection Systems 5
Requirements on Data Collection Systems 5
Achieving High Transfer Rates to Devices 6
Achieving High Transfer Rates to Disk 7
Real-Time Programming Languages 7

2. Basic Features of the CHALLENGE and IRIX™ Architectures 9
Multiprocessor Architecture 9
CPUs, Memory, and the System Bus 10
Concurrent Execution 11
Memory Hierarchy 11
Cache Coherency Updates 11
Virtual Memory 12
Translation Lookaside Buffer Updates 13
Device Interrupts 13
VME Interrupts 14
Interrupt Latency 14
Interrupt Response Time 14
Processor Arrays 15
Process Management 15
Process Composition 15
Process Creation 16
Normal Process Creation With fork() 16
Address Space Replacement With exec() 16
Lightweight Process Creation With sproc() 17
Process Scheduling 17
I/O Scheduling 18
Disk I/O 18
VME Bus I/O 19
Other I/O 19
Asynchronous I/O 19

3. How IRIX™ and REACT/Pro™ Support Real-Time Programs 21
Kernel Facilities for Real-Time Programs 21
Kernel Optimizations 22
Special Scheduling Disciplines 22
Nondegrading Priorities 22
Deadline Scheduling 23
Gang Scheduling 23
Processor Sets 23
Locking Virtual Memory 24
Mapping Processes and CPUs 24
Controlling Interrupt Distribution 25
REACT/Pro Frame Scheduler 25
How Frames Are Defined 26
Advantages of the Frame Scheduler 27
Designing With the Frame Scheduler 27
Interprocess Communication 29
Shared Memory Segments 29
IRIX Shared Memory Arenas 29
SVR4-Compatible Shared Memory 30
Semaphores 31
IRIX Semaphores 32
SVR4-Compatible Semaphores 32
Locks 33
Barriers 34
Mutual Exclusion Primitives 35
Signals 36
Signal Latency 38

Timers and Clocks 38
Timer Interrupts (Itimers) 38
BSD Itimers 38
POSIX Timers 39
Timestamps 40
Time of Day Timestamp 40
Hardware Cycle Counter 40
Interchassis Communication 41
Socket Programming 41
Message-Passing Interface (MPI) 41
Reflective Shared Memory 42
External Interrupts 42

4. Managing Virtual Memory in a Real-Time Program 43
Defining the Address Space 43
Address Space Boundaries 44
Page Numbers and Offsets 44
Address Definition 45
Address Space Limits 46
Page Validation 47
Read-Only Pages 47
Copy-on-Write Pages 48
Interrogating the Memory System 48
Locking Pages in Memory 49
Locking Functions 49
Locking Program Text and Data 50
Locking Mapped Files Into Memory 51
Reducing Cache Misses 52
Locality of Reference 52
Cache Mapping in Challenge/Onyx 53
Multiprocessor Cache Conflicts 54
Detecting Cache Problems 54

5. Managing Time and Time Intervals 55
Using Interval Timers 55
Timed Pauses 55
POSIX Timer Support 56
BSD Timer Support 56
Using an Itimer 57
Time Data Structures 58
Time Signal Latency 59
How Timers Are Managed 59
Timer Management in Challenge, Onyx, and POWER-Challenge 60
Timer Management Without a Clock Comparator 60
Using Short Timer Intervals 61
Fast Timers With a Clock Comparator 61
Fast Timers Without a Clock Comparator 61
Selecting the fasthz Value 62
Which CPU Handles Timer Interrupts 62
Using Timestamps 63
Using the Time of Day 63
Using BSD gettimeofday() 63
Using POSIX clock_gettime() 64
Using the Cycle Counter 65
Comparing the Timestamps 66

6. Controlling CPU Workload 67
Using Priorities and Scheduling Queues 67
Scheduling Concepts 68
Tick Interrupts 68
Time Slices 68
Priorities 69
Aging Priorities 69
Scheduler Queues 70
Setting a Nondegrading Batch Priority 70
Setting a Nondegrading Real-Time Priority 71
Understanding Affinity Scheduling 72
Using Gang Scheduling 73
Using Deadline Scheduling 74
Changing the Time Slice Duration 75
Using Processor Sets 76
Assigning a Process to a Processor Set 76
Assigning a Processor Set to a Queue 77
Assigning a Discipline to a Processor Set 78
Processor Set Contradictions 78
Minimizing Overhead Work 79
Assigning the Clock Processor 79
Assigning the fasthz Processor 79
Unavoidable Timer Interrupts 80
Isolating a CPU From Sprayed Interrupts 81
Assigning Interrupts to CPUs 81
Understanding the Vertical Sync Interrupt 82
Restricting a CPU From Scheduled Work 82
Assigning Work to a Restricted CPU 83
Isolating a CPU From TLB Interrupts 84
Isolating a CPU When Performer™ Is Used 86
Making a CPU Nonpreemptive 86

Minimizing Interrupt Response Time 87
Maximum Response Time Guarantee 87
Components of Interrupt Response Time 88
Hardware Latency 89
Software Latency 90
Kernel Critical Sections 90
Service Time for Other Devices 91
Device Service Time 91
Dispatch Cycle 92
Adjust Scheduler Queue 92
Switch Processes 92
Mode Switch 92
Minimal Interrupt Response Time 93

7. Using the Frame Scheduler 95
Frame Scheduler Concepts 96
Frame Scheduler Basics 96
Frame Scheduling 96
The FRS Control Process 98
The Frame Scheduler API 98
Library Interface for C Programs 99
System Call Interface for Fortran and Ada 100
Process Execution 101
Scheduling Within a Minor Frame 102
Scheduler Flags frs_run and frs_yield 102
Detecting Overrun and Underrun 103
Estimating Available Time 103
Using Multiple Synchronized Schedulers 104
Starting a Single Scheduler 104
Starting Multiple Schedulers 105
Pausing Frame Schedulers 105
Managing Activity Processes 106

Selecting a Time Base 107
On-Chip Timer Interrupt 107
High-Resolution Timer 108
Vertical Sync Interrupt 108
External Interrupts 108
Device Driver Interrupt 109
Software Interrupt 109
Using the Scheduling Disciplines 110
Realtime Discipline 110
Background Discipline 111
Underrunable Discipline 111
Overrunnable Discipline 111
Continuable Discipline 112
Using Multiple Consecutive Minor Frames 112
Preparing the System 113
Implementing a Single Frame Scheduler 114
Implementing Synchronized Schedulers 115
Syncronized Scheduler Concepts 115
Synchronized Schedulers: the Sync-Master Process 116
Synchronized Schedulers: Sync-Slave Processes 117
Handling Frame Scheduler Exceptions 118
Exception Types 118
Exception Handling Policies 118
Injecting a Repeat Frame 119
Extending the Current Frame 119
Dealing With Multiple Exceptions 119
Setting Exception Policies 119
Querying Counts of Exceptions 121
Using Signals Under the Frame Scheduler 122
Signal Delivery and Latency 122
Handling Signals in the FRS Controller 123
Handling Signals in an Activity Process 124
Setting Frame Scheduler Signals 124

Using Timers with the Frame Scheduler 125
The Frame Scheduler Device Driver Interface 126
Device Driver Overview 126
Exporting the Initialization and Termination Functions 127
Frame Scheduler Initialization Function 128
Frame Scheduler Termination Function 130
Generating Interrupts 131

8. Optimizing Disk I/O for a Real-Time Program 133
Memory-Mapped I/O 133
Asynchronous I/O 134
Conventional Synchronous I/O 134
Synchronous Input 134
Synchronous Output 135
Asynchronous I/O Basics 135
Two Implementation Versions 136
Asynchronous I/O Functions 137
Asynchronous I/O Control Block 137
Initializing Asynchronous I/O 138
Implicit Initialization 138
Initializing with aio_sgi_init() 138
When to Initialize 139
Scheduling Asynchronous I/O 140
Assuring Data Integrity 140
Checking the Progress of Asynchronous Requests 141
Polling for Status 141
Checking for Completion 142
Establishing a Completion Signal 142
Establishing a Callback Function 143
Holding Callbacks Temporarily 146
Multiple Operations to One File 146

Synchronous Writing and Direct Writing 147
Using Synchronous Writing 147
Using Direct I/O 148
Performance Comparison 148
Using a Delayed System Buffer Flush 150
Guaranteed-Rate I/O 150
Guaranteed-Rate I/O Basics 150
Creating a Real-time File 151
Requesting a Guarantee 153
Releasing a Guarantee 154
Sharing Access to Guaranteed Files 154
Hard Guarantees 155
Soft Guarantees 155
Video On Demand (VOD) Guarantees 156

9. Managing Device Interactions 157
Device Drivers 157
How Devices Are Defined 158
How Devices Are Used 158
Device Driver Entry Points 159
Taking Control of Devices 160
SCSI Devices 160
SCSI Hardware on CHALLENGE and Onyx Systems 161
SCSI Adapter Support 161
System Disk Device Driver 161
System Tape Device Driver 162
Generic SCSI Device Driver 162
CD-ROM and DAT Audio Libraries 163

The VME Bus 164
CHALLENGE Hardware Nomenclature 164
VME Bus Attachments 165
VME Address Space Mapping 166
PIO Address Space Mapping 167
DMA Mapping 167
Program Access to the VME Bus 168
PIO Access 168
User-Level Interrupt Handling 169
DMA Access to Master Devices 169
DMA Engine Access to Slave Devices 170
Serial Ports 172
External Interrupts 173

A. Sample Programs 175
Mapping and Reading the Cycle Counter 175
Testing Cycle Counter Precision. 176
Reading the Cycle Counter 177
Getting the Time of Day Stamp 184
Interprocess Communication 186
Probing the Address Space 198
Deadline Scheduling Subroutines 200
Asynchronous I/O Example 203
Guaranteed-Rate Request 221
Frame Scheduler Examples 225
Basic Example 226
Real-Time Application Specification 226
Frame Scheduler Design 226
Example of Scheduling Separate Programs 227
Examples of Multiple Synchronized Schedulers 229
Example of Device Driver 230
Examples of a 60 Hz Frame Rate 230
Example of Managing Lightweight Processes 231

Glossary 233

Index 241